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TESTING OF BAKER Flo-XS PIPELINE DRAG-REDUCING ADDITIVE

COMPILATION OF TESTS AND RESULTS

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Pipeline drag-reducing additives have been used for many years in crude oil and some products to increase throughput in the pipeline. In recent years, interest in using drag-reducing additives in jet fuel has increased because of greater demand on the petroleum product pipelines for jet fuel. Thus, testing was completed on the Baker Flo-XS pipeline drag-reducing additive to determine if the additive had any negative impact on the fuel. The proposed use of the additive was to add 2 ppm at up to 4 points along the pipeline(s). Thus, the majority of testing was completed using 8.8 ppm (8 ppm total plus 0.8 ppm for errors in injection). Through a CRADA with Buckeye Pipeline Inc, thermal stability testing of the additive was completed. Additionally, low temperature testing, additive/additive compatibility testing and specification testing of additized fuel was also completed. Material compatibility tesing was also taken into consideration.

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SUMMARY

Pipeline drag-reducing additives have been used for many years in crude oil and some products to increase throughput in the pipeline. In recent years, interest in using drag-reducing additives in jet fuel has increased because of greater demand on the petroleum product pipelines for jet fuel. Thus, testing was completed on the Baker Flo-XS pipeline drag-reducing additive to determine if the additive had any negative impact on the fuel. The proposed use of the additive was to add 2 ppm at up to 4 points along the pipeline(s). Thus, the majority of testing was completed using 8.8 ppm (8 ppm total plus 0.8 ppm for errors in injection). Through a CRADA with Buckeye Pipeline Inc, thermal stability testing of the additive was completed. Additionally, low temperature testing, additive/additive compatibility testing and specification testing of additized fuel was also completed. Material compatibility testing was also taken into consideration.

Since jet fuel is used as a coolant in aircraft, one concern with any new additive is the impact of the additive on the thermal stability properties of the fuel. Thus, thermal stability testing was the main concern for this set of tests. To capture the variety of jet fuel available, nineteen fuels were used. Testing techniques included the ICOT, QCM, HLPS, EDTST, NIFTR, Augmentor Simulator and ARSFSS. Based on the results of testing at a polymer concentration of 8.8 ppm, the Baker FLO XS drag-reducing additive had no deleterious impact on thermal stability of jet fuel up to 325°F bulk and 450°F wetted wall temperature. When added to the +100 additive package at the same concentration, it had no deleterious impact on thermal stability up to 375°F bulk and 500°F wetted wall conditions. Based on the results of the screening tests using a wide variety of fuels, Baker FLO XS is not sensitive to fuel types or treatments. The additional tests also showed no deleterious impact on the jet fuel. Material compatibility was considered, but was determined to not be necessary.

INTRODUCTION

The American Petroleum Institute (API) conducted a survey in 1997 that showed over 40% of the pipelines dedicated to jet fuel use in the US will be at maximum capacity in the next 10 years [1]. This is due to the forecasted increased demand for jet fuel by the commercial airlines. Many of the pipelines that deliver commercial jet fuel also deliver jet fuel to Air Force bases. In addition, the operators of over 80% of the existing multi-product pipelines need to increase throughput in order to move sufficient product to meet demand during the same time period. The delivery of the additional volume of jet fuel can be achieved in a number of ways. Additional pipelines could be built or alternative transportation modes such as tank trucks could be used. Both of these options are costly and will ultimately increase the price of jet fuel. The API survey results indicate that to construct additional pipelines to meet demand will cost in excess of $500M. Fulfilling the increased demand by truck transportation is even more costly. A third alternative is the use of a pipeline drag-reducing additive (DRA) in the jet fuel in the existing lines to achieve the desired throughput. This alternative has generated interest because drag reducing additives have already been used in crude oil and some of its other products. The third alternative is the driving force of this testing.

Thermal stability testing was performed on the Baker Flo XS pipeline drag-reducing additive (AFRL/PRSF identification number POSF-3597) to determine any negative impact of the additive on fuel properties. The test matrix used was developed through discussions at American Society of Testing and Materials (ASTM) Committee D-2 meetings. A cooperative research and development agreement was created between Buckeye Pipeline and the Air Force Research Laboratory, Propulsion Directorate, Propulsion Sciences and Advanced Concepts Division, Fuels Branch. In this agreement, thermal stability tests developed during the JP-8+100 program in order to screen potential +100 additives were used to study POSF-3597.

The test hardware, protocols and conditions used were developed by the Air Force over many years as the +100 program developed in order to evaluate the acceptability of fuel additives for use in aircraft. Equipment manufacturers input was also considered during development of the testing. This series of tests was very successful in screening the potential additives for the JP-8+100 and reducing the risk of full-scale engine and aircraft testing [2].

Additional testing beyond that described in the CRADA was also completed. Specification testing of a variety of the test fuels was completed at various concentrations of the Baker Flo-XS additive to determine if the additive has any impact. Also, low temperature testing was completed to determine any low temperature impact of the additive. The low temperature properties were a concern because of the additive's high weight.

BAKER FLO-XS

Baker Flo-XS is a 12.5% solution of a 70/30 (w/w) copolymer of 1-dodecene/1-hexene in isopentane. The testing was completed using a polymer dosage of 8.8 ppm into jet fuel. At this dosage, residual catalyst hetero atoms in the jet fuel are Ti (0.8-1.1 ppb), Al (9.6-15.9 ppb) and Cl (12.0-19.1 ppb) [3]. Because the polymer is difficult to get into solution, Baker Chemical diluted the 12.5% polymer solution to a 1% polymer level using a high-grade kerosene for the laboratory testing. To achieve the 8.8 ppm needed for testing, 0.80 was assumed to be the density of the fuel. Assuming that density, 704 mg/L of the 1% polymer additive was used.

TASKS

The screening tests were the Isothermal Corrosion/Oxidation Test, the Quartz Crystal Microbalance and the Hot Liquid Process Simulator. After the screening tests, the larger Extended Duration Thermal Stability Test was completed on two test fuels with POSF-3597 as well as one test with POSF-3597 + Betz 8Q462 (+100) additive at the more rigorous +100 conditions. The Advanced Reduced Scale Fuel System Simulator (ARSFSS) was completed on one test fuel with POSF-3597. Other tests included the Augmentor Fouling Simulator, the Near-Isothermal Flowing Test Rig, Low Temperature testing, specification testing, additive/additive compatibility and material compatibility. The standard additization rate was 8.8 ppm polymer. This rate assumed a maximum additization of 8 ppm total over the length of the pipeline with the 0.8 ppm added to cover injection inaccuracy. The 8.8 ppm rate was chosen because the pipelines determined that the most useful rate would be adding 2 ppm at 4 different points throughout the pipeline.

METHODS, ASSUMPTIONS and PROCEDURES

&

RESULTS and DISCUSSIONS

SECTION I. SCREENING TESTS

ISOTHERMAL CORROSION/OXIDATION TEST

The Isothermal Corrosion/Oxidation Test (ICOT) is a static thermal stability experiment. Figure I.1-1 shows a basic schematic of the test apparatus.

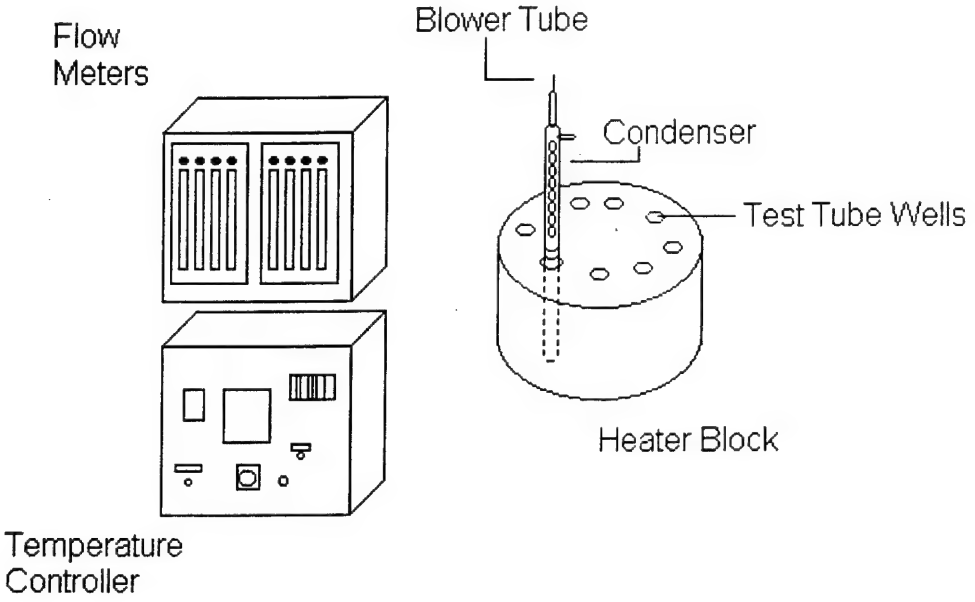


Figure I.1-1. Isothermal Corrosion/Oxidation Test Apparatus

In a typical experiment, the heater block temperature is set at 180°C. Once 180°C is maintained, a test tube with 100 mL of fuel is placed into a tube well in the heating block. A condenser is attached to the test tube and a glass blower tube is inserted down the middle of the condenser. A continuous supply of dry air is sparged into the fuel at a rate of 1.3 L/hr via tygon tubing connecting the glass blower tube with the flow meter. The sample is thermally and oxidatively stressed for 5 hours. At the end of 5 hours, the air is turned off, the condenser detached, and the test tube removed from the heating block. The sample is allowed to cool overnight. The next day, the sample is vacuum filtered through a pre-weighed 0.7 μm glass fiber filter. The bulk particulates collected on the filter are rinsed with heptane to remove any remaining fuel. The filter is placed in an oven at 100°C for several hours to completely dry the filtered material. It is then removed from the oven and placed in a dessicator to cool before weighing. The effect of an additive is based on the difference between the bulk insolubles formed from the neat fuel and the bulk insolubles formed from the additized fuel. Repeatability of the ICOT test is $^{+}$/- 20% [4].

Figure I.1-2 shows the results from all the fuels tested, additized at 8.8 ppm polymer, including the 20% error bars. Table I.1-1 shows the numerical results of the same tests.

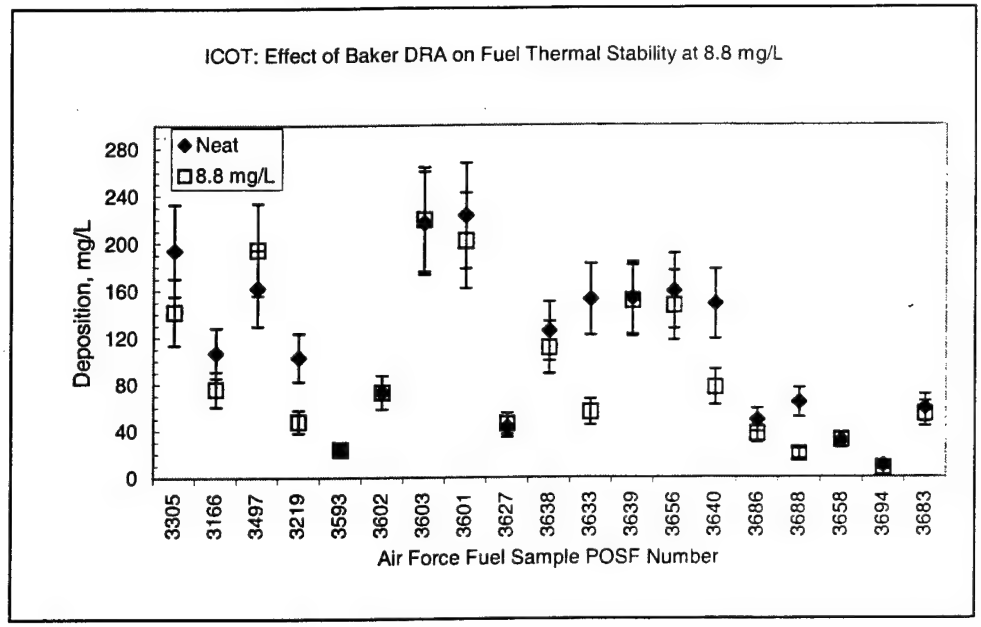


Figure I.1-2. ICOT Results—8.8 ppm polymer

Fuel Sample Identification	ICOT (mg/L) Neat Fuel	ICOT (mg/L) Fuel + 8.8 ppm DRA
96-POSF-3305	194	142
95-POSF-3166	107	76
98-POSF-3497	162	195
96-POSF-3219	103	48
99-POSF-3593	24	24
99-POSF-3602	73	73
99-POSF-3603	217	220
99-POSF-3601	223	202
99-POSF-3627	43	46
99-POSF-3638	125	111
99-POSF-3633	152	56
99-POSF-3639	153	151
99-POSF-3656	159	147
99-POSF-3640	148	77
99-POSF-3686	49	37
99-POSF-3688	64	20
99-POSF-3658	31	32
99-POSF-3694	10	8
99-POSF-3683	59	54

Table I.1-1. ICOT Results—8.8 ppm polymer

Within the uncertainty of the test, the addition of 8.8 ppm POSF-3597 results in ICOT insolubles that are the same as, or lower than, the baseline fuels. Thus, all the fuels tested at 8.8 ppm had acceptable results for this screening test.

Other tests were completed using 35.2 ppm (4 times the 8.8 concentration) and the results are shown in Figure I.1-3. The numerical data is shown in Table I.1-2.

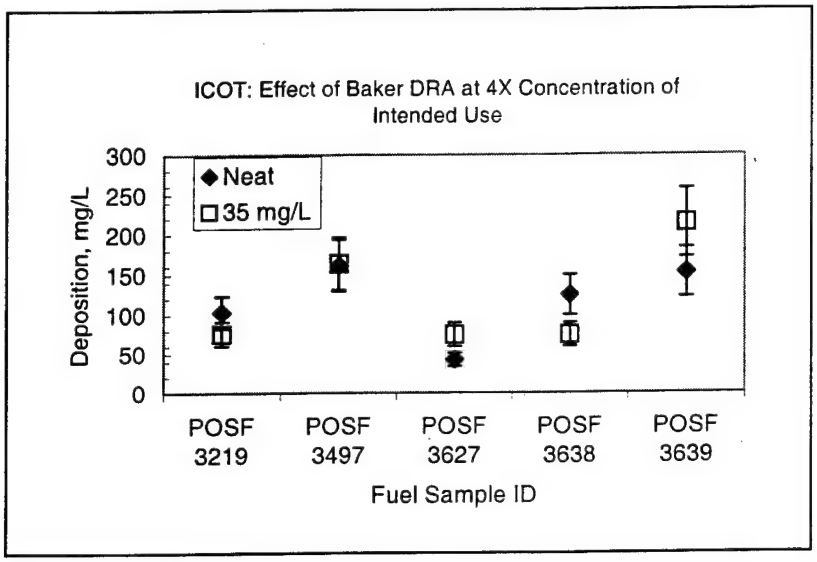


Figure I.1-3. ICOT Results—4x Original Concentration

Fuel Sample Identification	ICOT (mg/L) Neat Fuel	ICOT (mg/L) Fuel + 35 ppm DRA
96-POSF-3219	103	76
98-POSF-3497	162	164
99-POSF-3627	43	75
99-POSF-3638	125	75
99-POSF-3639	153	215

Table I.1-2. ICOT Results—4x Original Concentration

Within the uncertainty of the test, the addition of 35.2 ppm POSF-3597 results in ICOT insolubles that are the same as, or lower than, the baseline fuels in all but one fuel. This fuel, POSF-3627, is a hydrotreated fuel which yields relatively low deposition in both tests. The presence of the additive increases the deposition only slightly outside the 20% error bars at this 4x concentration. The bulk insolubles formed from the 4x concentration of the additive are still quite low relative to other unadditized fuels. Thus, these data show that addition of the additive at either the 1x or 4x concentration is unlikely to produce significant changes in fuel thermal stability.

2. QUARTZ CRYSTAL MICROBALANCE

The Quartz Crystal Microbalance is a static test that monitors both deposition and oxidation during the thermal stressing of a jet fuel. Figure I.2-1 shows a cross-section schematic of the test apparatus.

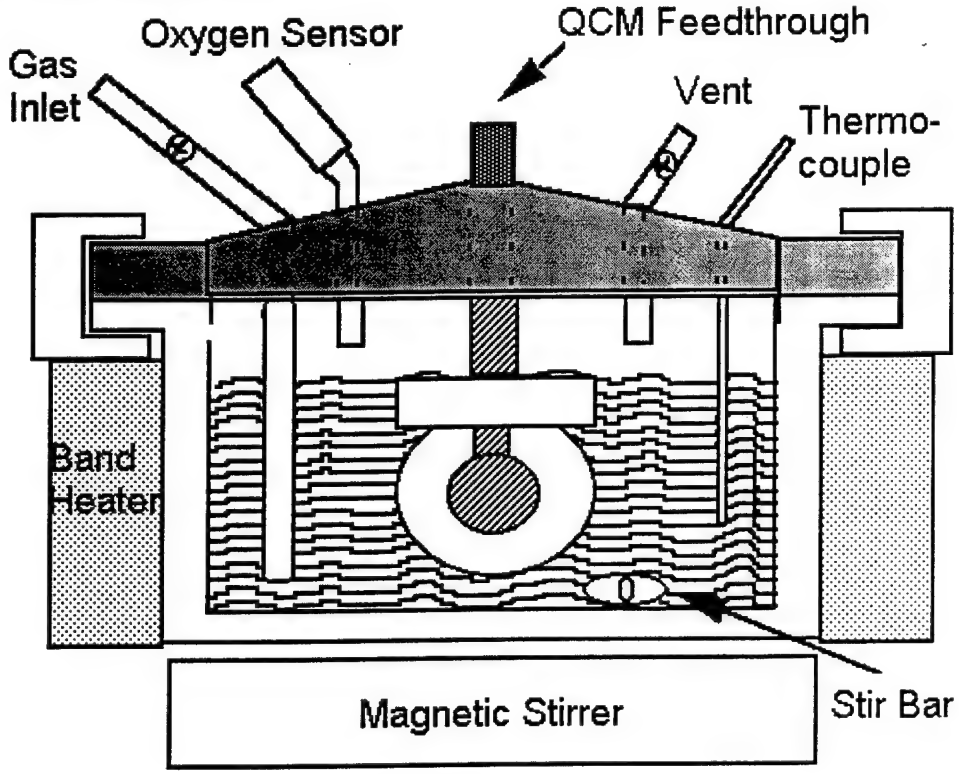


Figure I.2-1. Quartz Crystal Microbalance Schematic

A quartz crystal microbalance is used to measure the deposition while a polarographic oxygen sensor is used to monitor oxidation. The Parr bomb is a 100 mL stainless steel reactor. It is heated with a clamp-on band heater and its temperature is controlled by a PID controller through a thermocouple immersed in the fuel. The reactor contains an rf feedthrough, through which the connection for the quartz crystal resonator is attached. The crystals are 2.54 cm in diameter, 0.33 mm thick and have a nominal resonant frequency of 5 MHz. Mass deposition is monitored as a decrease in the resonant frequency of the crystal. The QCM measures deposition (i.e., an increase in mass) which occurs on overlapping sections of the two-sided electrodes. Thus, the device responds to deposition that occurs on the metal surface and does not respond to deposition on the exposed quartz.

The device is also equipped with a pressure transducer (Sensotec) to measure the absolute headspace pressure and a polarographic oxygen sensor (Ingold) to measure the headspace oxygen concentration. A personal computer is used to acquire data at one-minute intervals during the experimental run. The following data are recorded during a

run: temperature, crystal frequency, headspace pressure, headspace oxygen concentration, and crystal damping voltage.

The reactor is charged with 60 mL of fuel, which is sparged with the appropriate gas for one hour before each test. The reactor is then sealed and the heater is started. All runs in this study were performed at 140°C; heat-up time to this temperature is 40±5 minutes. Most runs are conducted for 15 hours, after which the heater is turned off and the reactor allowed to cool. Surface mass measurements can only be determined during the constant temperature (±0.2°C) portion of an experimental run [5]. Figure I.2-2 shows the results from all the fuels tested, additized at 8.8 ppm polymer, including the 20% error bars. Table I.2-1 shows the numerical results.

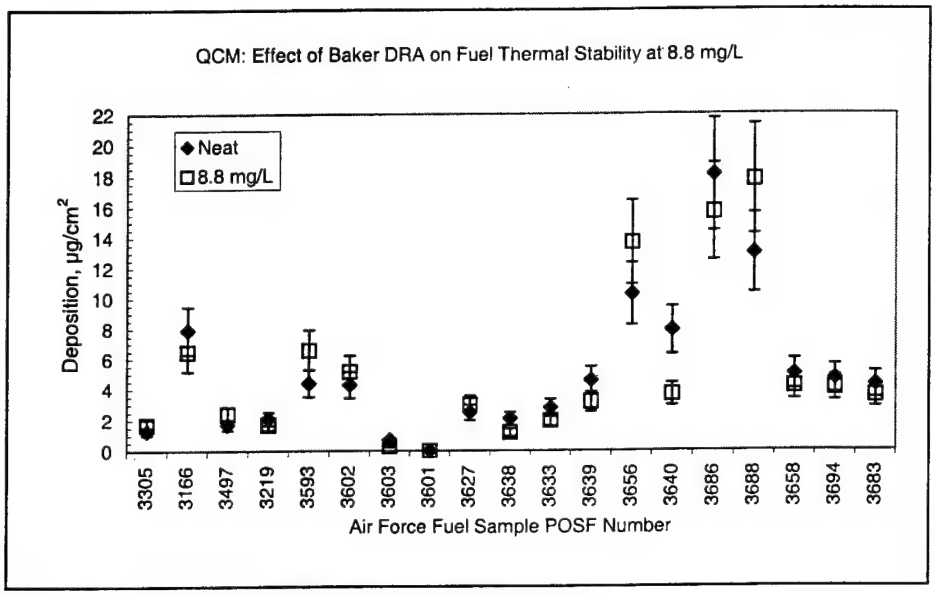


Figure I.2-2. QCM Results—8.8 ppm Polymer

Fuel Sample Identification	QCM (µg/cm^2) Neat Fuel	QCM (µg/cm^2) Fuel + 8.8 ppm DRA
96-POSF-3305	1.3	1.7
95-POSF-3166	7.9	6.5
98-POSF-3497	1.7	2.4
96-POSF-3219	2.1	1.7
99-POSF-3593	4.4	6.6
99-POSF-3602	4.3	5.2
99-POSF-3603	0.7	0.3
99-POSF-3601	0	0
99-POSF-3627	2.5	3
99-POSF-3638	2.1	1.2
99-POSF-3633	2.8	2
99-POSF-3639	4.6	3.2

99-POSF-3656	10.3	13.7
99-POSF-3640	7.9	3.7
99-POSF-3686	18.1	15.7
99-POSF-3688	13	17.8
99-POSF-3658	5	4.2
99-POSF-3694	4.7	4.1
99-POSF-3683	4.3	3.6

Table I.2-1. QCM Results—8.8 ppm polymer

Within the uncertainty of the test, the addition of 8.8 ppm POSF-3597 results in QCM deposits that are the same as, or lower than, the baseline fuels. Thus, all the fuels tested at 8.8 ppm had acceptable results for this screening test.

Other tests were completed using 35.2 ppm (4 times the 8.8 concentration) and the results are shown in Figure I. 2-3 with the numerical results in Table I.2-2.

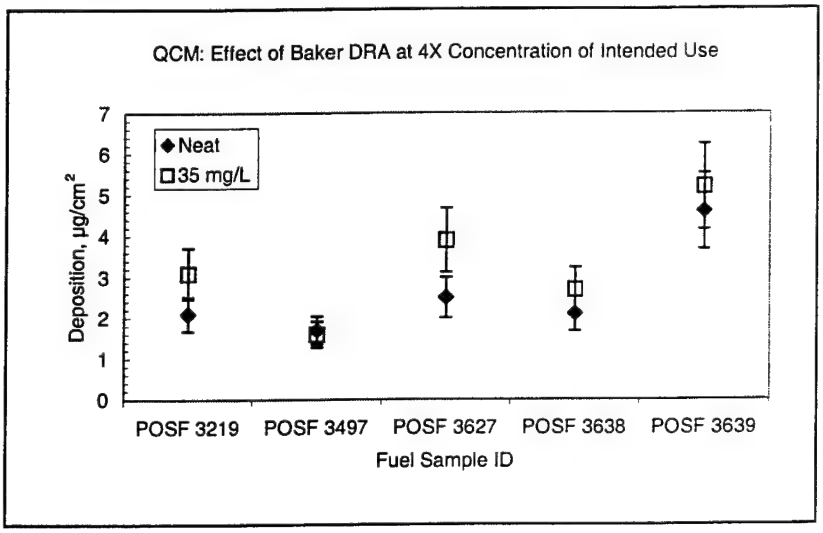


Figure I. 2-3. QCM Results—4x Original Concentration

Fuel Sample Identification	QCM (µg/cm^2) Neat Fuel	QCM (µg/cm^2) Fuel + 35 ppm DRA
96-POSF-3219	2.1	3.1
98-POSF-3497	1.7	1.6
99-POSF-3627	2.5	3.9
99-POSF-3638	2.1	2.7
99-POSF-3639	4.6	5.2

Table I.2-2. QCM Results—4x Original Concentration

In the 4x concentration, POSF 3627 yields a higher deposition with the additive present in the QCM as well. Again, this fuel is a hydrotreated fuel that yields relatively low deposition in both tests. The presence of the additive increases the deposition only

slightly outside the 20% error bars for both tests at the 4x concentration. Most importantly, the fuel deposition with the 4x concentration of the additive is still quite low relative to other unadditized fuels. For example, some fuels used by the Air Force in aircraft have had QCM deposition levels of 10 $\mu g/cm^2$ and above. Thus, these data show that addition of the additive at either the 1x or 4x concentration is unlikely to produce significant changes in fuel thermal stability.

3. HOT LIQUID PROCESS SIMULATOR

The Hot Liquid Process Simulator (HLPS) is a derivative of the Jet Fuel Thermal Oxidation Tester (JFTOT) employed in ASTM D 3241 to rate the tendencies of aviation turbine fuels to form deposits under thermal-oxidative stress. A schematic of the HLPS is shown in Figure I.3-1.

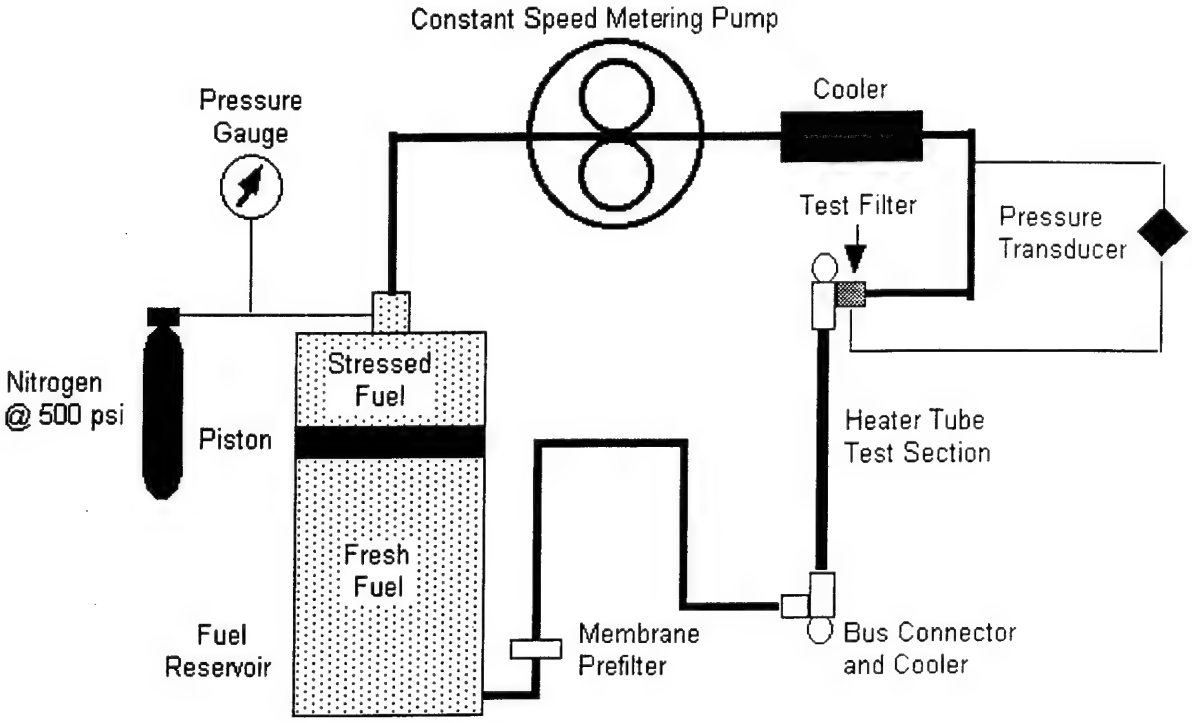


Figure I.3-1. Hot Liquid Process Simulator Schematic

The test conditions selected to evaluate additive performance are much more severe than those specified in the standard JFTOT procedure. Tests are performed at 335°C for 5 hours at a flow rate of 3 mL/min. Series 316 stainless steel tubes are substituted for the conventional aluminum tubes to permit quantitation of the deposit by carbon burnoff using a LECO RC-412 Carbon Analyzer [6]. Differences in deposition show additive effects. Figure I.3-2 shows the results for all the fuels tested. Table I.3-1 shows the numerical results for those tests.

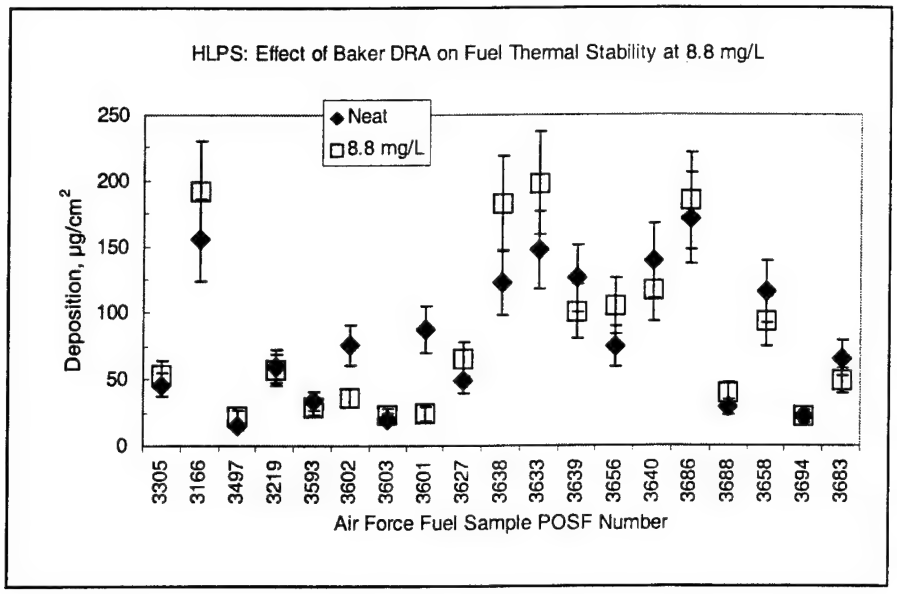


Figure I.3-2. HLPS Results—8.8 ppm polymer

Fuel Sample Identification	HLPS (µg/cm^2) Neat Fuel	HLPS (µg/cm^2) Fuel + 8.8 ppm DRA
96-POSF-3305	46	54
95-POSF-3166	155	192
98-POSF-3497	15	22
96-POSF-3219	60	57
99-POSF-3593	34	29
99-POSF-3602	76	36
99-POSF-3603	20	23
99-POSF-3601	88	24
99-POSF-3627	49	65
99-POSF-3638	123	182
99-POSF-3633	147	198
99-POSF-3639	126	101
99-POSF-3656	75	105
99-POSF-3640	139	117
99-POSF-3686	171	184
99-POSF-3688	29	40
99-POSF-3658	116	93
99-POSF-3694	22	22
99-POSF-3683	66	49

Table I.3-1. HLPS Results—8.8 ppm polymer

Within the uncertainty of the test, the addition of 8.8 ppm POSF-3597 results in HLPS deposits that are the same as, or lower than, the baseline fuels. Thus all the fuels tested at 8.8 ppm had acceptable results for this screening test.

Other tests were completed using 32 ppm (4 times the 8 concentration). This rate was the actual intention for the 4x tests. The 0.8 was added to the initial screening tests to cover additive injection error. When the 4x tests were developed, it was decided that additization error would be covered in the much greater amount of polymer added to the fuel. However, AFRL/PRSF did not receive that word in time. The QCM and ICOT tests were already completed. Thus there is a slight difference between the additization rates for the HLPS and the other screening tests. The results of the 4x concentration tests are shown in Figure I.3-3 and the numerical data is shown in Table I.3-2.

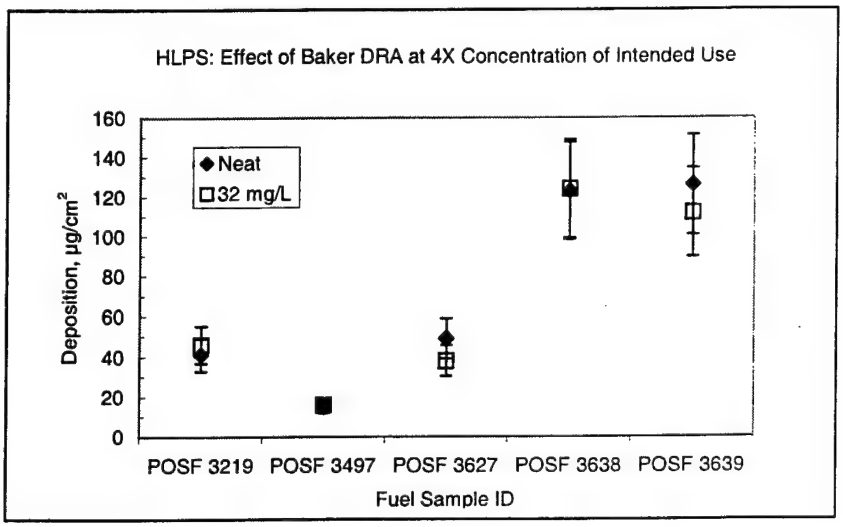


Figure I.3-3. HLPS Results—4x Original Concentration

Fuel Sample Identification	HLPS ($\mu g/cm^2$) Neat Fuel	HLPS ($\mu g/cm^2$) Fuel + 32 ppm DRA
96-POSF-3219	41	46
98-POSF-3497	15	16
99-POSF-3627	49	38
99-POSF-3638	123	124
99-POSF-3639	126	112

Table I.3-2. HLPS Results—4x Original Concentration

Within the uncertainty of the test, the addition of 32 ppm POSF-3597 results in HLPS deposits that are the same as the deposits for the baseline fuels. An interesting point is that the low depositing POSF-3627 that was showing a slight increase in the

ICOT and QCM tests, did not show the same increase in the HLPS test. These data show that addition of the additive at either the 1x or 4x concentration is unlikely to produce significant changes in fuel thermal stability.

4. FUELS USED DURING TESTING

A wide variety of jet fuels were used in this testing program. Because a matrix of jet fuels had already been determined for red dye contamination of jet fuel testing, the same set of fuels was used for this program. Table I.4-1 shows the red dye fuels used (reported as four digit POSF numbers) and how they were processed.

Processing	Light Crude Sweet	Light Crude Sour	Mixed Crude	Heavy Crude Sweet	Heavy Crude Sour
Str-Run No Treatment	3638				
Str-Run Clay Treated	3633				
Srt-Run Sweetened Merox	3639 3694				
Srt-Run Sweetened Blender Treated	3593				
Srt-Run Doctor Sweetened	3656				
Srt-Run Hydrotreated	3640	3603	3601	3602	3627
Hydrocracked			3658 3688		3686
Thermal Cracked, HT			3683		

Table I.4-1 Processing of Red Dye Test Fuels Used

Thus, a wide variety of fuels were tested in the screening tests. Comparing the screening test results, especially for the samples that were processed similarly, does not indicate a pattern suggesting that any given type of fuel is sensitive to Baker DRA.

METHODS, ASSUMPTIONS, and PROCEDURES

&

RESULTS and DISCUSSIONS

SECTION II. SIMULATION TESTS

1. EXTENDED DURATION THERMAL STABILITY TEST

The EDTST was established to provide fuel thermal stability information for designers in addition to evaluating fuels. Figure II.1-1 shows a schematic of the EDTST.

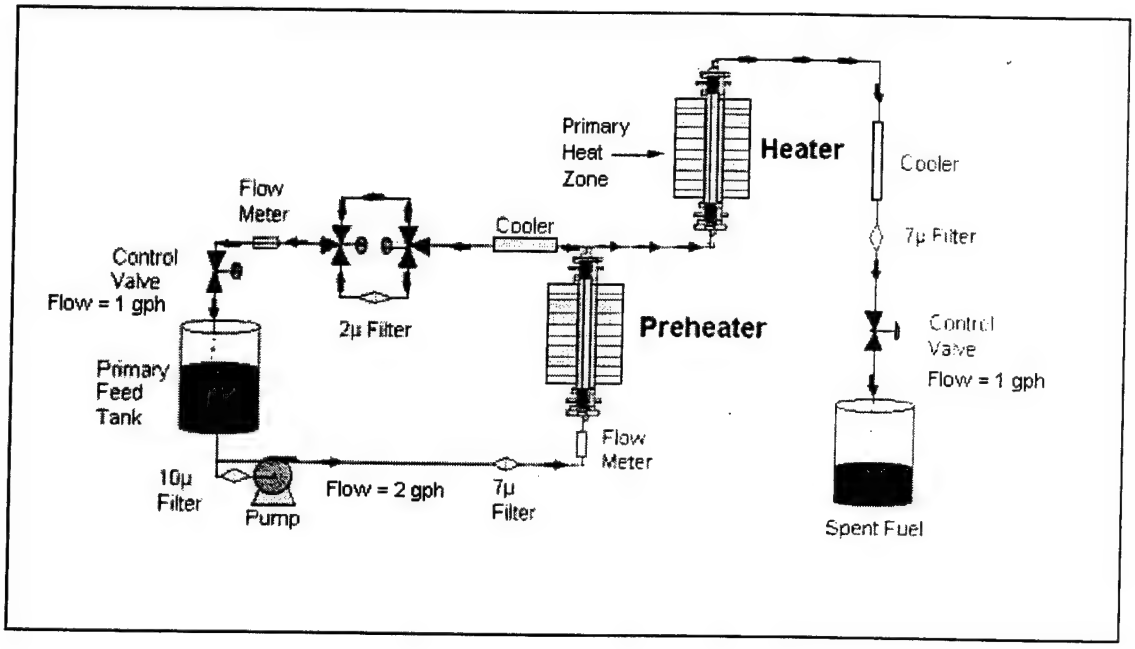


Figure II. 1-1. EDTST Schematic

The system consists of a 60 gallon feed tank, an electrical motor driven gear pump, two clamshell furnace heaters, and a scrap tank. The first furnace heater (preheater) in the system is used to establish the desired fuel bulk temperature into the second heater and to establish the desired fuel bypass temperature. The fuel bulk temperature represents the temperature that results from aircraft and engine heat loads. The second furnace heater (main heater) establishes the wetted wall temperatures associated with engine injection nozzles.

Both furnace heaters are 0.81 meters long and resistance heated. A typical main heater assembly is shown in Figure II.1-2. Both heaters have 5 heating element zones that are independently controlled. The fuel flows upward through a single stainless steel tube in each heater. The tube in the preheater has an O.D. of 1.27 cm and a wall thickness of 0.0889 cm. The tube in the main heater has an O.D. of 0.32 cm and a wall thickness of 0.0889 cm. Each tube is assembled inside a thick walled furnace tube that has an I.D. of 2.54 cm and an O.D. of 5.08 cm. The tubes have thermocouples attached to the outer wall for measuring wetted wall temperatures. The annular space between the furnace tube and heater tubes is filled with sand.

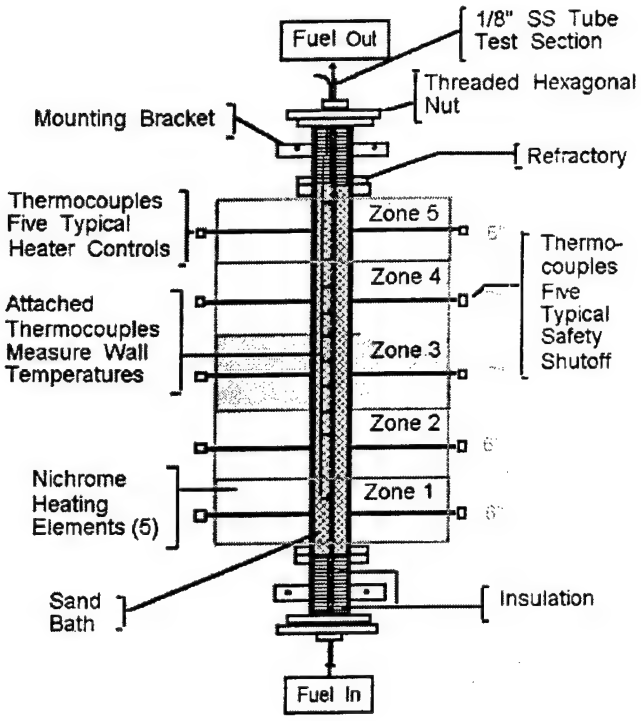


Figure II.1-2. EDTST Heater

A fuel bypass line is installed downstream of the preheater to represent the aircraft recirculation line from the engine to the airframe tanks. A water/fuel cooler is installed in this line to represent the aircraft ram air heat exchanger. A 2μ filter is also installed in the line for 4 hours to measure particles in the recirculated bulk fuel. Since studying the effects of recirculation is one of the purposes of this test, the filter is installed only for a short duration. Aircraft fuel systems will probably not have a filter in the recirculation line. A 7μ filter is also installed downstream of the heater. This filter provides an indication of particles that the fuel nozzles will experience in future engines where a heat exchanger is downstream of the engine fuel controls.

The flow rate into the preheater is 2 gallons per hour (gph). The flow is split at the exit of the preheater such that 1 gph is delivered to the main heater and 1 gph to the bypass flow line. The residence time from the inlet of the preheater to the outlet of the main heater is approximately 50 seconds. The residence time from the inlet to the outlet of the main heater is 1.1 seconds with a Reynolds number of ~2,400. This residence time is representative of those in aircraft and engine fuel systems. The typical test period for an EDTST run is 96 hours [7].

The series of tests for POSF-3597 included testing in two different fuels as well as testing with the +100 additive package at +100 conditions. The two fuels used were POSF-3219 and POSF-3166, both Jet-A fuels. Tests were conducted with and without POSF-3597 in both fuels at 325°F bulk and 450°F wetted wall temperature conditions. An additization rate of 8.8 ppm polymer was used for these tests. All tests were

conducted for a 96-hour duration. The carbon deposits in the preheater and heater tubes for these tests are shown in Figure II.1-3.

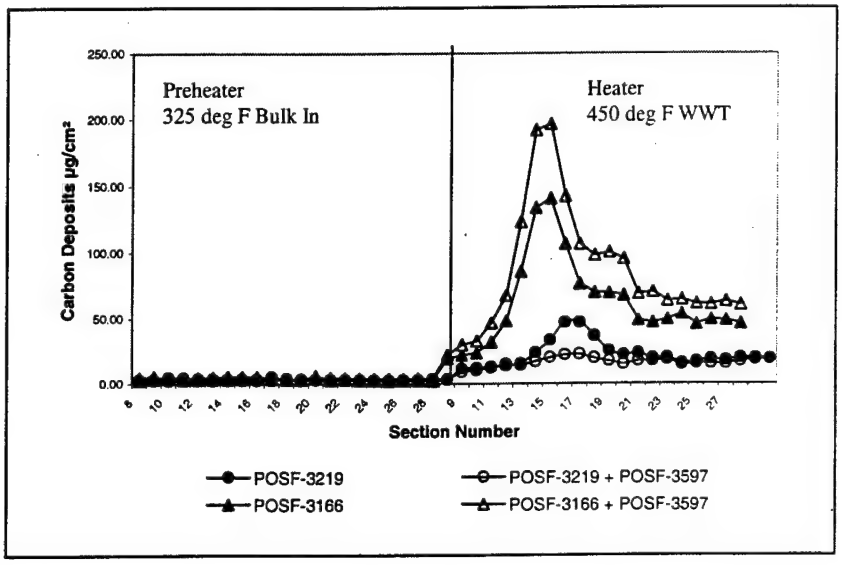


Figure II.1-3. EDTST using POSF-3219 and POSF-3166: Preheater and Heater Sections

The additive had slightly lower deposits in POSF-3219 and slightly higher deposits in POSF-3166 fuel. However, these differences are within the uncertainty of the test.

Another test was conducted with POSF-3597 in POSF-3219 fuel that had both the JP-8 additives and the Betz 8Q462 additive. This test was to determine if POSF-3597 would effect the thermal stability of JP-8+100 fuel. Again, 8.8 ppm polymer additization rate was used. This test was conducted at 375°F bulk and 500°F wetted wall temperature conditions. The carbon deposits in the preheater and heater tubes for this test are shown in Figure II.1-4. Results of a previous run of the same fuel at the same conditions only without POSF-3597 are shown in this figure for comparison purposes.

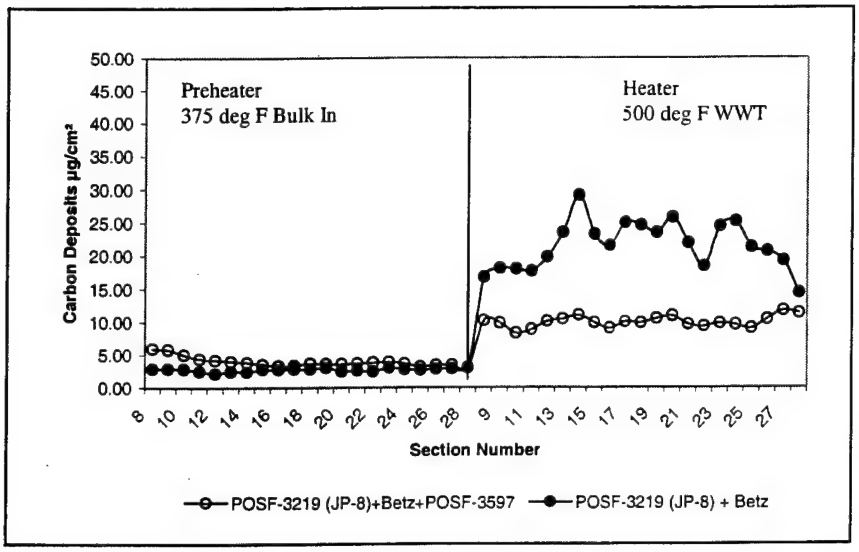


Figure II.1-4. EDTST using POSF-3219 + Betz 8Q462 + POSF-3597: Preheater and Heater

The differences between the two are within the uncertainty of the test. Based on these results, POSF-3597 is unlikely to degrade the thermal stability of Jet A or JP-8+100 fuels.

2. AUGMENTOR FOULING SIMULATOR

The augmentor simulates the leaking or residual fuel in the augmentor injection system of a military aircraft. Figure II.2-1 shows a schematic of the augmentor simulator.

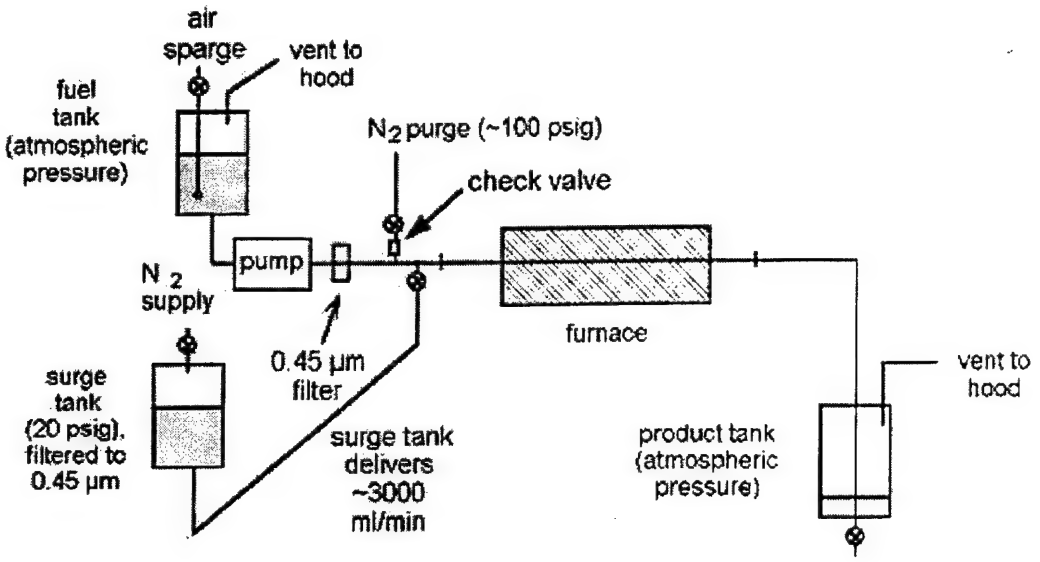


Figure II.2-1. Augmentor Simulator Schematic

The fuel is fed by a SSI 222C HPLC pump to a ¼ in. outer diameter 316-type stainless steel tubing (0.035 in. wall thickness) which passes through a T-intersection containing a Parker 5 µm filter. From there, the tubing enters a Lindberg 55035 heater that heated the fuel to 550°C. Thermocouples are placed along the stainless steel tubing approximately every 2 inches inside the heater to ensure temperature requirements are met to vaporize the fuel. The tube drops ¼ in. from the inlet of the heater to the outlet. Before beginning each test run, the system is purged with nitrogen for approximately 2 minutes to rid it of any oxygen. The fuel flow is established at 1.5 mL/min and is constant for the duration of the run. After the test period of 15 hrs, the tube is sectioned and the deposition determined by carbon burnoff in a LECO RC-412 Multiphase carbon determinator [8].

Two fuels were tested, POSF-3219 and POSF-3497. The standard test value of 8.8 ppm polymer of POSF-3597 was used.

The largest deposit always occurs at the point where the fuel vaporizes. In this test, that point is at 15.24 cm down the tube length. This deposit is created by all of the insoluble and high-boiling material formed by thermal-oxidative reactions.

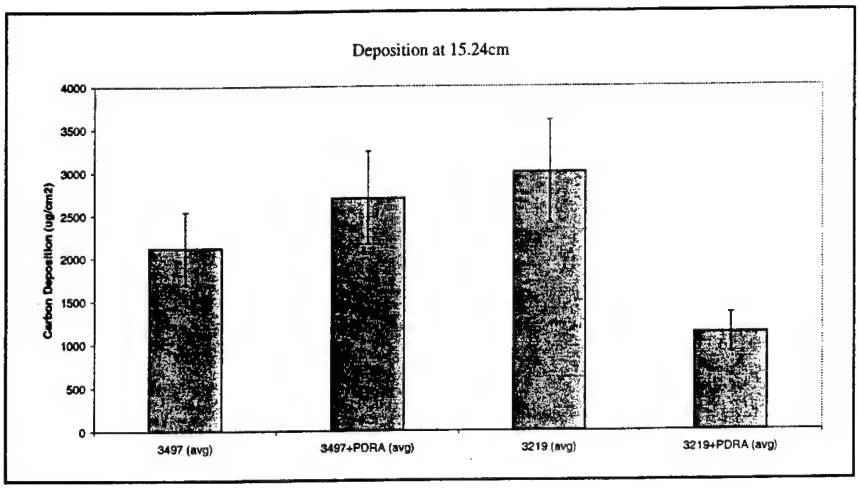


Figure II.2-2. Augmentor Deposition at 15.24 cm

As shown in Figure II.2-2, addition of POSF-3597 to POSF-3219 fuel slightly lowered the deposition at 15.24 cm while addition to POSF-3497 fuel caused a slight increase in the deposition. The increase was within the uncertainty of the test (20 %). Thus, this test agrees with the earlier tests that the additive is unlikely to damage thermal stability when 8.8 ppm polymer additization is used.

3. NEAR-ISOTHERMAL FLOWING TEST RIG

The NIFTR uses dynamic isothermal techniques to evaluate additives. Using this technique, the dependence of both dissolved oxygen and surface deposition can be monitored as a function of stress or reaction time under isothermal conditions of 185°C. In addition, the bulk insolubles are evaluated over the complete reaction time. A diagram of the NIFTR is shown in Figure II.3-1.

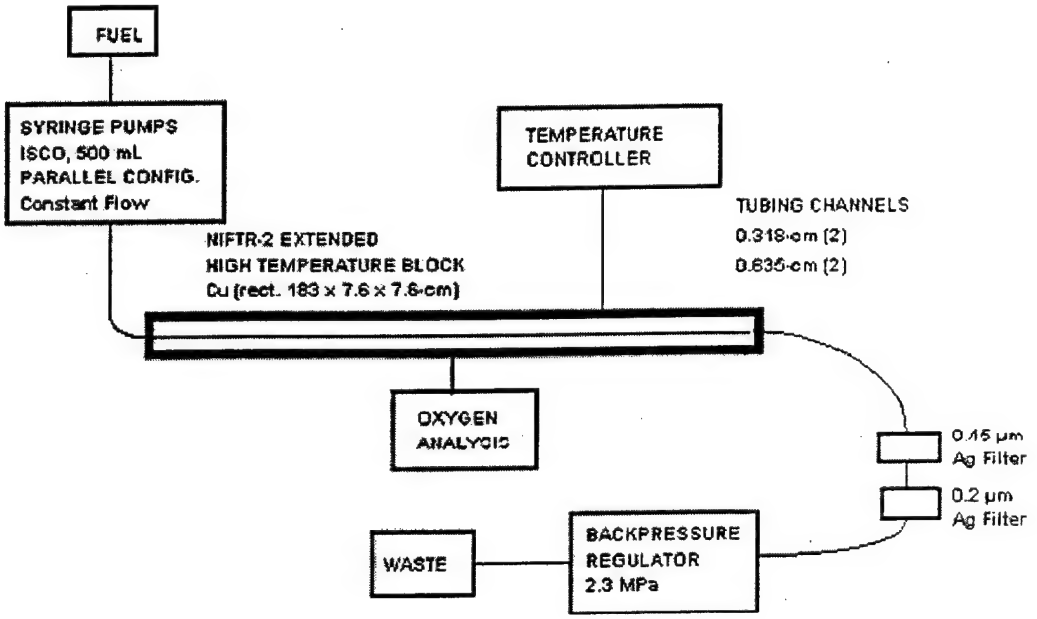


Figure II.3-1. NIFTR Schematic

The fuel flows through heated tubing at pressures above 2.3 MPa ensuring a single reaction phase and simulating fouling that occurs in aircraft. Typically, experiments are conducted to allow depletion of all dissolved oxygen and completion of the corresponding deposition processes. This is usually accomplished in 23 min of stressing at 185°C.

Oxidation and deposition experiments are performed in different experiments, briefly summarized in the following:

Oxidation: Fuel is passed through 32 in of passivated tubing maintained at constant wall temperature by a heat exchanger. Fuel residence time is changed by varying fuel flow rate. Concentration of O_2 is determined by GC. 100 % corresponds to air-saturated fuel.

Deposition: Fuel flows at 0.25 mL/min through 72 in of 0.125-in outer diameter, 0.085-in inner diameter stainless steel tubing. Tubing walls are maintained at 185°C by the Cu-block heat exchanger. The test lasts 72 hours and uses 1.08 L fuel. Surface and bulk carbon are determined by surface carbon burnoff of tube sections and in-line filters.

Stress duration is proportional to distance along the tube and is calculated assuming plug flow. Quantity of insolubles is expressed in units of μg/mL [9].

The NIFTR results for deposition and oxidation are shown in Figures II.3-2 and II.3-3. From a deposition standpoint neat JP-8, Jet-A and additized Jet-A are approximately the same within experimental uncertainty yielding 1.53, 1.68, and 1.47 μg/mL, respectively. The in-line bulk insolubles, however, are significantly reduced in the additized sample, compared to either the neat JP-8 or Jet-A (compare 0.11 with 0.64 and 0.84). These results suggest some detergent/dispersant properties of POSF-3597 in this fuel.

The JP-8 additive package tends to be slightly pro-oxidant as we have seen in other fuels. However, the oxidation changes from the POSF-3597 are more pronounced. The POSF-3597 has distinct antioxidant behavior at 185°C as evidenced by the factor of 2 delay in the oxidation time. Overall, POSF-3597 appears to enhance the fuel behavior.

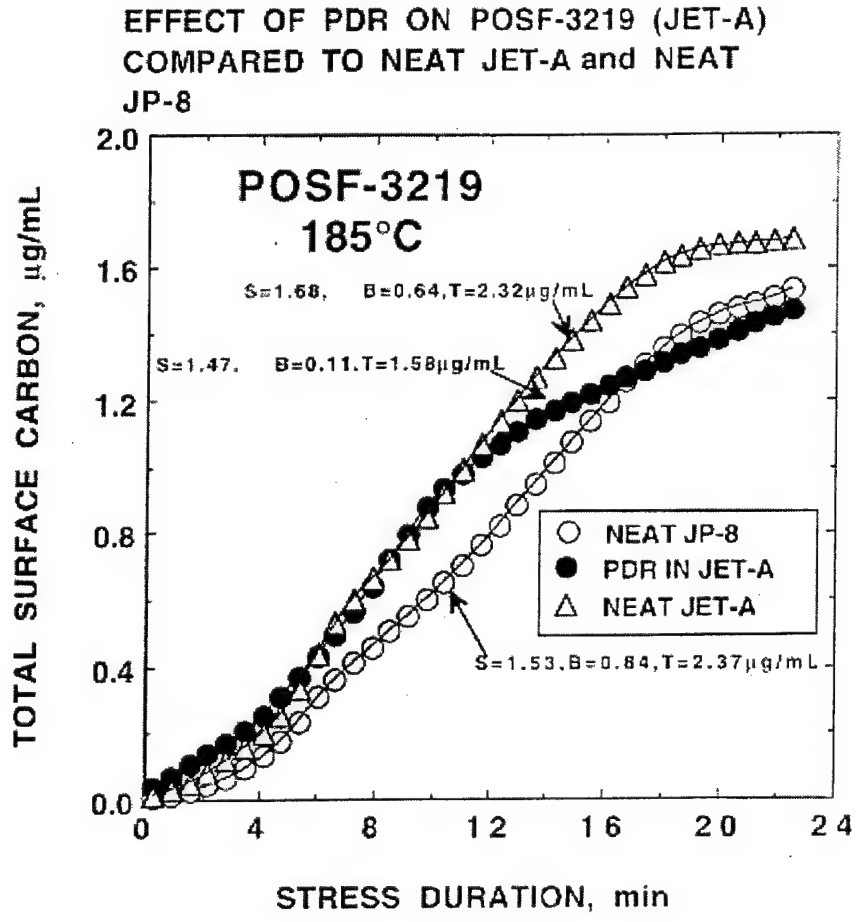


Figure II. 3-2. NIFTR Deposition Results

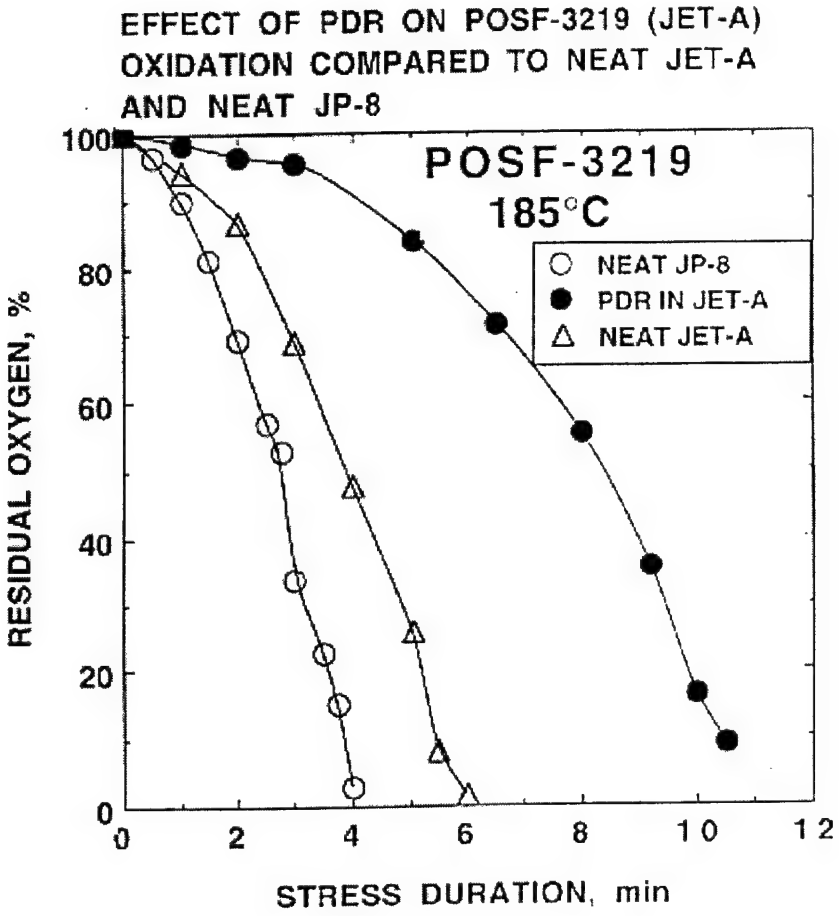


Figure II.3-3. NIFTR Oxidation Results

4. ADVANCED REDUCED SCALE FUEL SYSTEM SIMULATOR

The ARSFSS simulates the thermal performance and flow profile of turbine engine fuel systems, including engine hardware. The simulator consists of three integrated subsystems: 1) the fuel conditioning system, 2) the airframe fuel system, and 3) the engine fuel system. A schematic of the simulator is shown in Figure II.4-1.

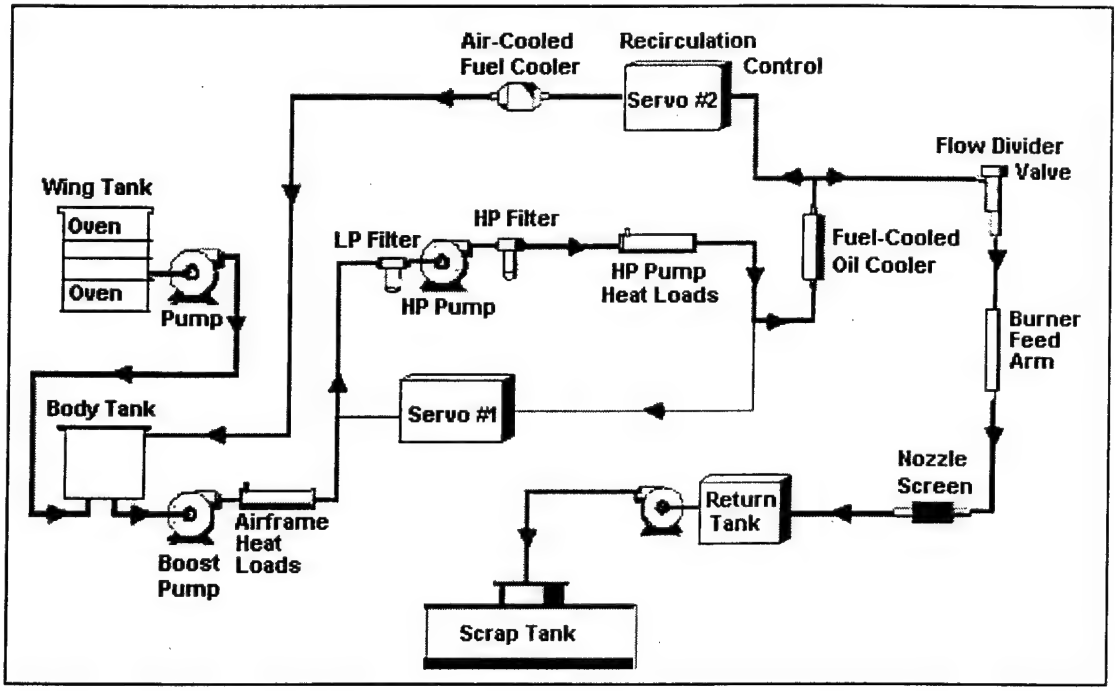


Figure II.4-1. ARSFSS schematic

The simulator was configured to simulate the F-22 aircraft with the F119 engine. The fuel flow established in the simulator is 1/72 scale of the F119 engine and the burn flow is 1/3 of the flow for a single F119 fuel nozzle. The total fuel required for each test is approximately 1,500 gallons.

Real-world engine components are incorporated into the engine portion of the simulator to help evaluate the impact of fuel deposits on component performance. The two real world components are both servo valves. The first servo valve bypasses flow back to the tank providing for recirculation. The second is the flow divider valve, which controls flow to the burner feed arm. Both valves are actual F119 components that have been modified for reduced flow by changing the slot width. The performance of the valves is determined by hysteresis before and after the test.

Two other components of interest are the fuel-cooled oil cooler (FCOC) and the burner feed arm (BFA). These components are simulated on the ARSFSS and are incorporated to study thermal stability effects. The FCOC represents the engine lube system cooler. It consists of an induction heater and a steel manifold with three 3/8î tubes and associated thermocouples. The tubes are connected and provide for three passes

through the heater. The tube that is used for the final pass is removed after each test. It is cut into 2 inch segments and subjected to carbon analysis. The burner feed arm is RF induction heated. It consists of a steel clamshell with a 1/8 inch stainless steel tube installed in middle of the clamshell. Thermocouples on the outside of the tube are positioned along the entire length to measure the temperature profile of the tube. At the end of the tests, this tube is cut up into 1 inch segments and subjected to carbon analysis as well [7].

A test of POSF-3597 was evaluated at conditions of 325°F bulk fuel out of the FCOC and a wetted wall temperature of 450°F. These conditions were selected to simulate worst case conditions that today's engine experience using Jet-A fuels. This test was conducted with POSF-3219 fuel with the POSF-3597 drag reducer additive at 8.8 ppm. The modified duty cycle was used and 65 missions (approximately 150 hours) were conducted for this test. The servo and flow divider valves were disassembled after this test and were in as-new condition. The hysteresis tests of these valves also indicated no change in valve performance. Plots of these tests are shown in Figures II.4-2 and II.4-3. The carbon deposits on the FCOC and burner feed arm tubes are shown in Figures II.4-4 and II.4-5. Data from a previous test of POSF-3219 fuel with the Betz 8Q462 additive is shown for reference purposes. The JP-8+100 test level demonstrates an acceptable amount of deposition. As seen in Figures II.4-4 and II.4-5, the carbon deposits from the POSF-3597 test were in the same acceptable range. Based on the results of this test, the drag reducer is considered to be thermally stable at bulk temperatures up to 325°F and 450°F wetted wall temperatures.

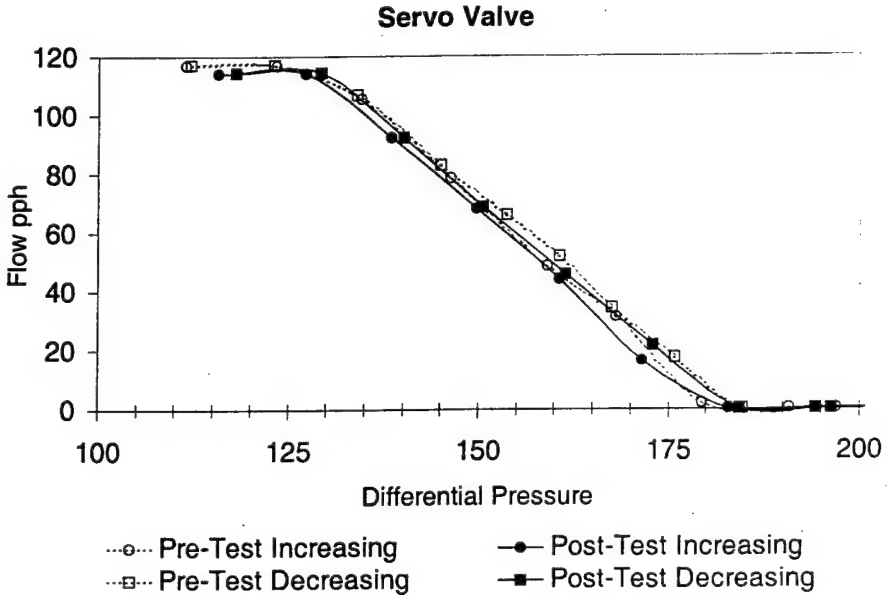


Figure II.4-2. Hysteresis Results for Servo Valve

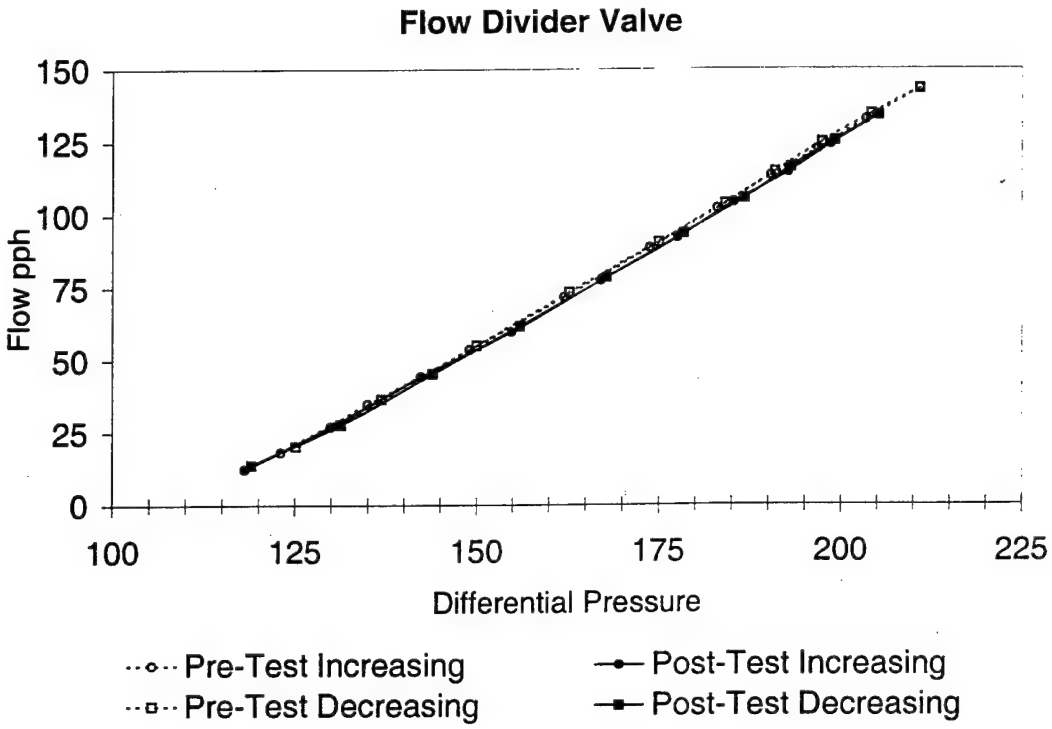


Figure II.4-3. Hysteresis Results for the Flow Divider Valve

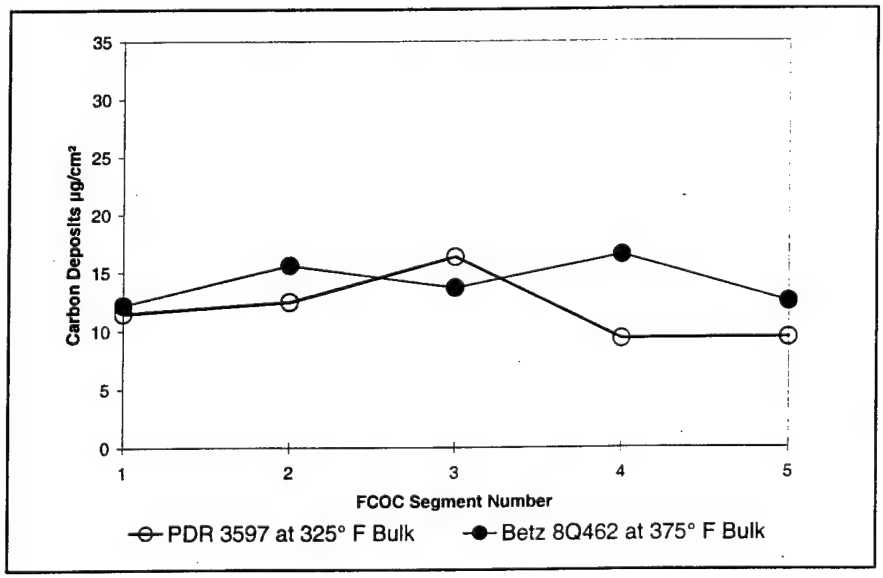


Figure II.4-4. Carbon Burnoff of the Fuel Cooled Oil Cooler

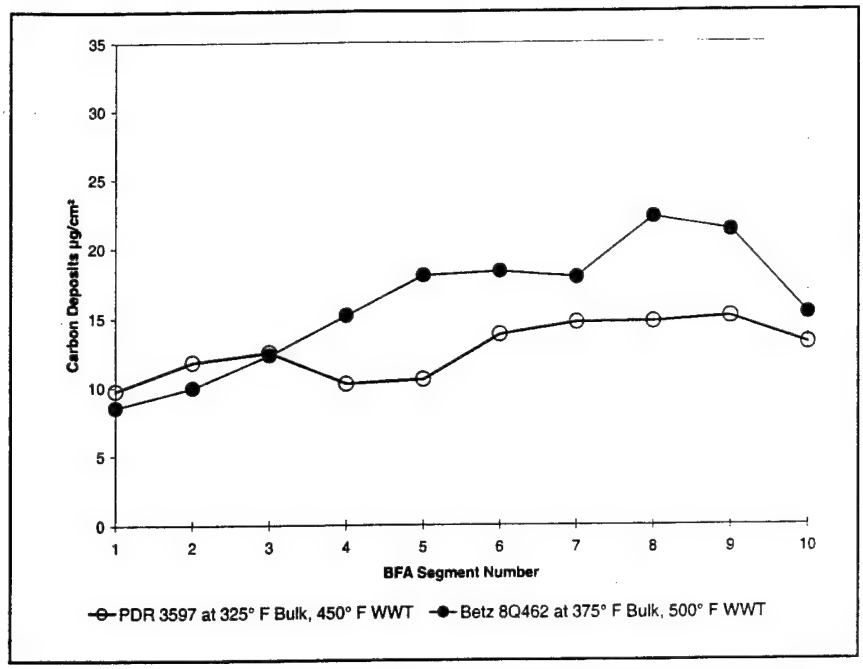


Figure II.4-5. Carbon Burnoff of the Burner Feed Arm

METHODS, ASSUMPTIONS, and PROCEDURES

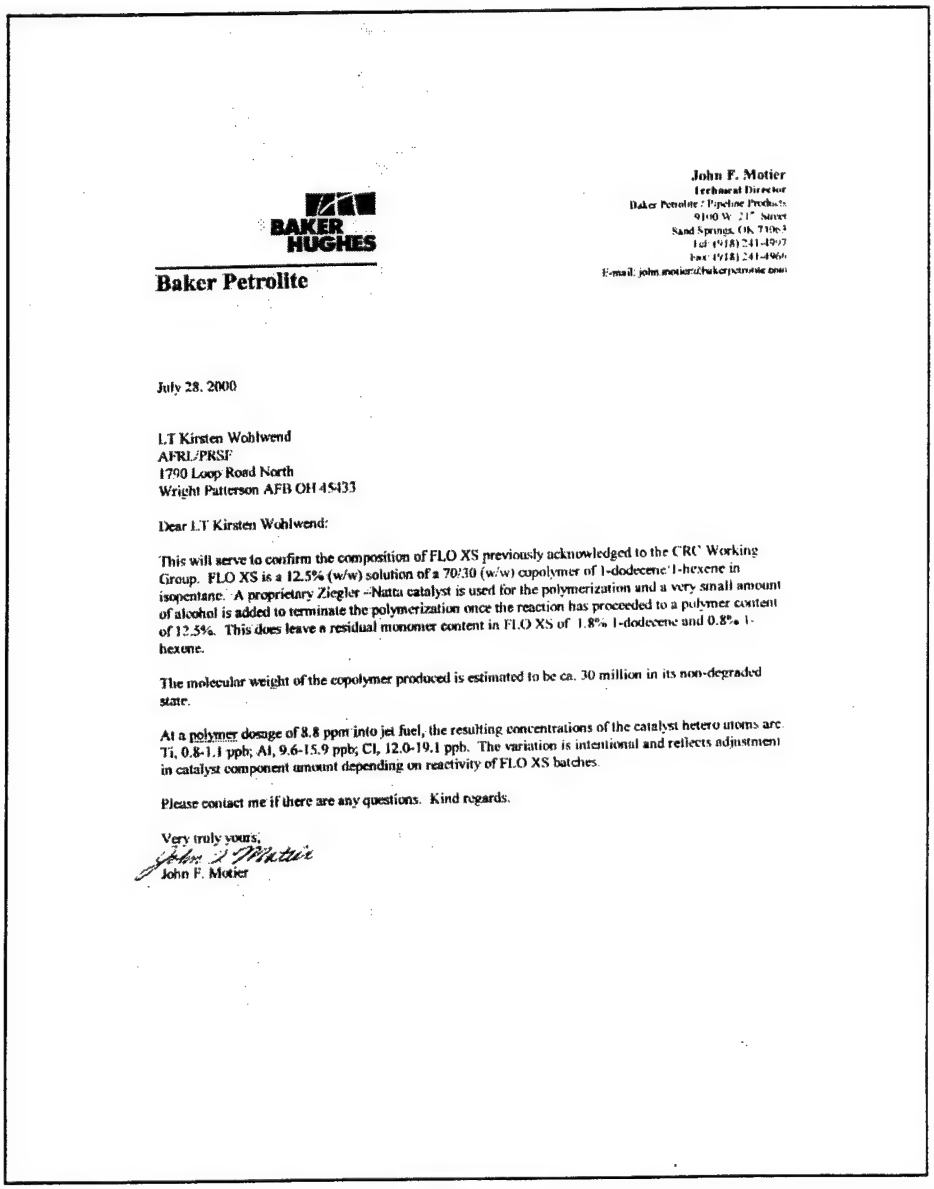
&

RESULTS and DISCUSSIONS

SECTION III. OTHER TESTS

1. MATERIAL COMPATIBILITY

The composition of Baker DRA was studied by Alan Fletcher of the Materials Behavior and Evaluation Section of the Materials Directorate, Air Force Research Laboratory. He determined that the additive does not have material compatibility issues and thus, material compatibility testing was not necessary. Figure III.1-1 is a letter from John Motier of Baker Petrolite / Pipeline Products describing the composition of Baker DRA (FLO XS). Figure III.1-2 is a letter from Lt Kirsten Wohlwend, AFRL/PRSF, to Alan Fletcher, AFRL/MLSA, requesting a material compatibility review of Baker DRA. Figure III.1-3 is Alan Fletcher's response, determining that Baker DRA is compatible with all aircraft fuel system materials and will not require material compatibility testing.



BAKER HUGHES

Baker Petrolite

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Tel: (918) 241-4907
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E-mail: john.motier@bakerpetrolite.com

July 28, 2000

LT Kirsten Wohlwend
AFRL/PRSF
1790 Loop Road North
Wright Patterson AFB OH 45433

Dear LT Kirsten Wohlwend:

This will serve to confirm the composition of FLO XS previously acknowledged to the CRC Working Group. FLO XS is a 12.5% (w/w) solution of a 70/30 (w/w) copolymer of 1-dodecene/1-hexene in isopentane. A proprietary Ziegler –Natta catalyst is used for the polymerization and a very small amount of alcohol is added to terminate the polymerization once the reaction has proceeded to a polymer content of 12.5%. This does leave a residual monomer content in FLO XS of 1.8% 1-dodecene and 0.8% 1-hexene.

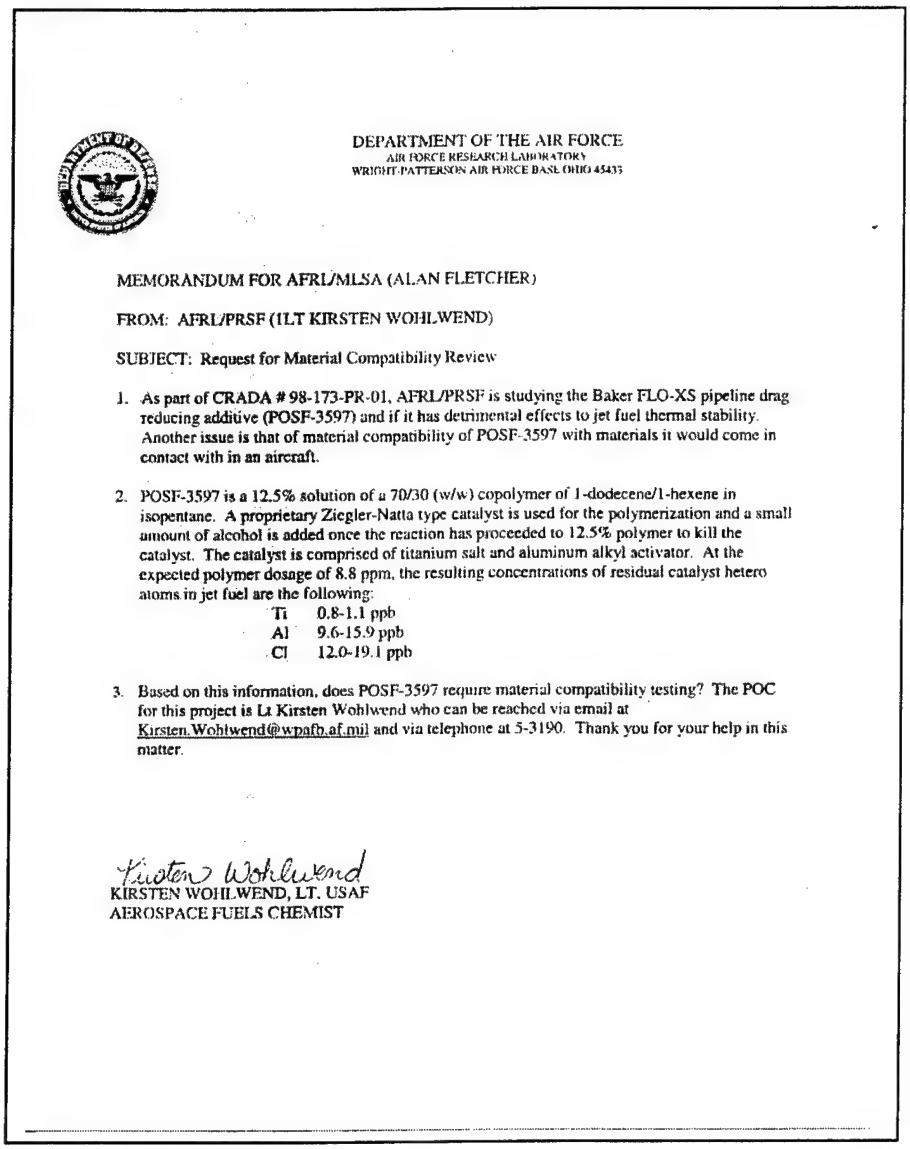
The molecular weight of the copolymer produced is estimated to be ca. 30 million in its non-degraded state.

At a polymer dosage of 8.8 ppm into jet fuel, the resulting concentrations of the catalyst hetero atoms are Ti, 0.8-1.1 ppb; Al, 9.6-15.9 ppb; Cl, 12.0-19.1 ppb. The variation is intentional and reflects adjustment in catalyst component amount depending on reactivity of FLO XS batches.

Please contact me if there are any questions. Kind regards.

Very truly yours,
John F. Motier
John F. Motier

Figure III.1-1. Baker DRA (FLO XS) composition letter from Baker Petrolite



DEPARTMENT OF THE AIR FORCE
AIR FORCE RESEARCH LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433

MEMORANDUM FOR AFRL/MLSA (ALAN FLETCHER)

FROM: AFRL/PRSF (1LT KIRSTEN WOHLWEND)

SUBJECT: Request for Material Compatibility Review

1. As part of CRADA # 98-173-PR-01, AFRL/PRSF is studying the Baker FLO-XS pipeline drag reducing additive (POSF-3597) and if it has detrimental effects to jet fuel thermal stability. Another issue is that of material compatibility of POSF-3597 with materials it would come in contact with in an aircraft.

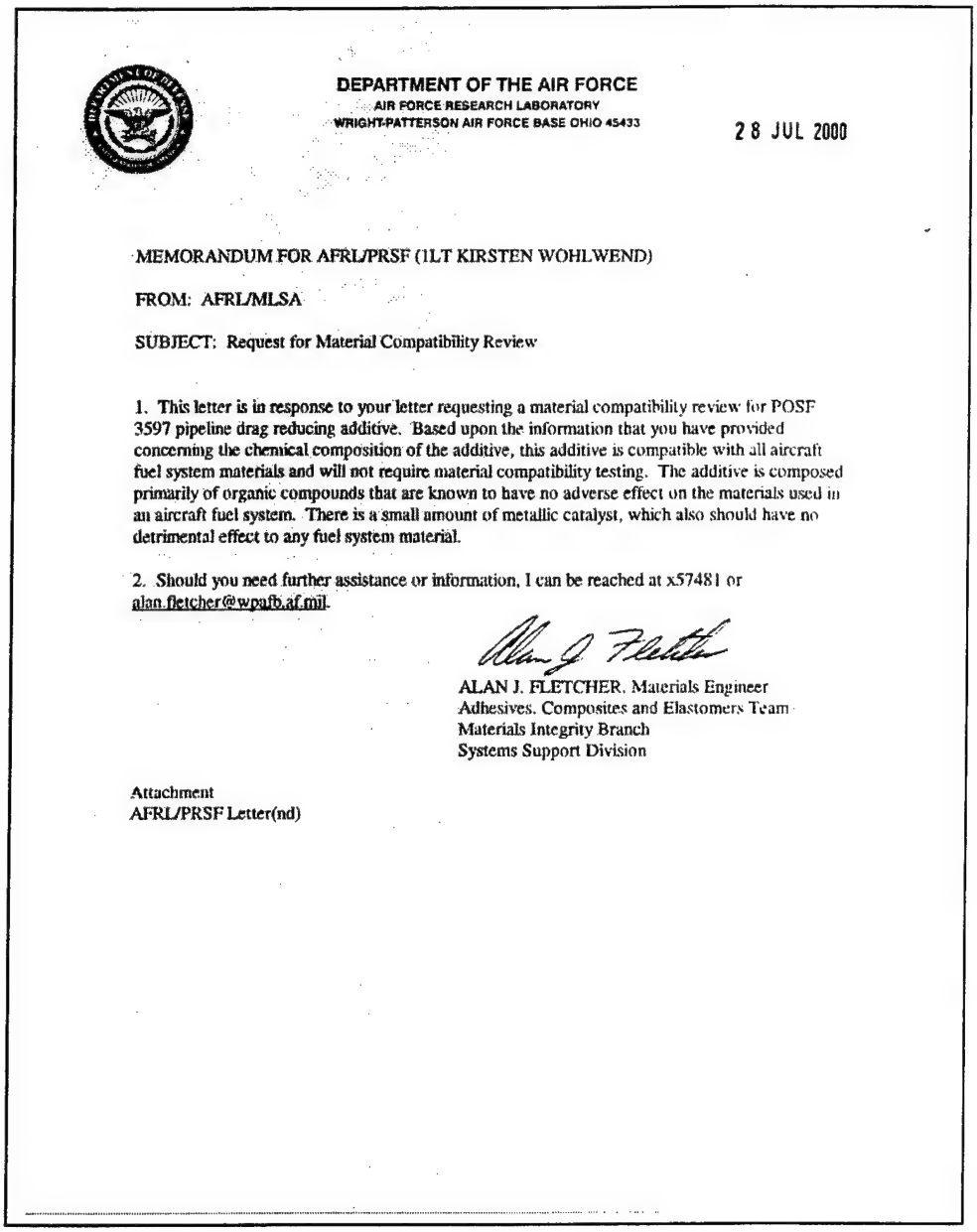
2. POSF-3597 is a 12.5% solution of a 70/30 (w/w) copolymer of 1-dodecene/1-hexene in isopentane. A proprietary Ziegler-Natta type catalyst is used for the polymerization and a small amount of alcohol is added once the reaction has proceeded to 12.5% polymer to kill the catalyst. The catalyst is comprised of titanium salt and aluminum alkyl activator. At the expected polymer dosage of 8.8 ppm, the resulting concentrations of residual catalyst hetero atoms in jet fuel are the following:

Ti	0.8-1.1 ppb
Al	9.6-15.9 ppb
Cl	12.0-19.1 ppb

3. Based on this information, does POSF-3597 require material compatibility testing? The POC for this project is Lt Kirsten Wohlwend who can be reached via email at Kirsten.Wohlwend@wpafb.af.mil and via telephone at 5-3190. Thank you for your help in this matter.

Kirsten Wohlwend
KIRSTEN WOHLWEND, LT. USAF
AEROSPACE FUELS CHEMIST

Figure III.1-2. Request to AFRL/MLSA for Material Compatibility Review



DEPARTMENT OF THE AIR FORCE
AIR FORCE RESEARCH LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433

28 JUL 2000

MEMORANDUM FOR AFRL/PRSF (1LT KIRSTEN WOHLWEND)

FROM: AFRL/MLSA

SUBJECT: Request for Material Compatibility Review

1. This letter is in response to your letter requesting a material compatibility review for POSF 3597 pipeline drag reducing additive. Based upon the information that you have provided concerning the chemical composition of the additive, this additive is compatible with all aircraft fuel system materials and will not require material compatibility testing. The additive is composed primarily of organic compounds that are known to have no adverse effect on the materials used in an aircraft fuel system. There is a small amount of metallic catalyst, which also should have no detrimental effect to any fuel system material.

2. Should you need further assistance or information, I can be reached at x57481 or alan.fletcher@wpafb.af.mil.

ALAN J. FLETCHER, Materials Engineer
Adhesives, Composites and Elastomers Team
Materials Integrity Branch
Systems Support Division

Attachment
AFRL/PRSF Letter(nd)

Figure III.1-3. Response from AFRL/MLSA

2. ADDITIVE/ADDITIVE COMPATIBILITY

A slightly modified ASTM Standard D 4054 procedure B was completed on POSF-3597 using POSF-3219 as the base fuel. First the base fuel was clay treated. The base fuel was separated into 100 mL portions. Baker FLO XS was added to one set of the portions at 35 ppm (4 times 8.8 ppm). Corrosion Inhibitor (DCI 4A), Fuel System Icing Inhibitor and a static dissipator (Stadis 450) were all added at four times their respective maximum allowable concentration to the other portions of base fuel. Each 100 mL portion of base fuel plus FLO XS was then blended with the corresponding 100 portion of base fuel plus approved additives. These resulting mixtures had 2 times the maximum recommended concentration of FLO XS and 2 times the maximum allowable concentration of the mil spec additives. The sample was then divided into two 100 mL portions. The samples were then placed in cold storage (-15.5°C / 4°F) for 24 hours. The samples were visually inspected after removal to look for indications of incompatibility (precipitation, cloudiness, darkening, separation etc). The samples were then warmed, shaken to make sure components were still mixed, and placed in an oven (75°C / 164°F) for 24 hours. The samples were removed and inspected for visual indications of incompatibility. They were then allowed to cool to room temperature and again inspected. No indications of precipitation, cloudiness, darkening or other visual evidence of incompatibility ever appeared.

3. SPECIFICATION TESTING

Specification testing was completed on a variety of the fuels used in the screening tests. Screening tests were performed on eleven of the neat test fuels. Specification testing was completed on nine of those fuels additized with 8.8 ppm Baker FLO XS. Additional specification testing was completed on five of the fuels using a polymer concentration of 35.2 ppm. The results of those tests are shown in Table III.3-1.

The addition of Baker Flo XS did not cause any of the samples to become out of specification, even at the higher concentrations of the additive. One area of interest is existent gum. While the addition of Flo XS at 35.2 ppm did not cause the fuel to become out of specification, for four of the five fuels used for high concentration testing, there was an increase. Additional testing was completed on the two fuels with the largest difference. The increase hit a plateau at 26 ppm (3x concentration) and the plateau was confirmed at 44 ppm (5x concentration). The 2 x concentration level was not tested. Because the increase hit a plateau instead of continuing to increase as more additive was added, it is not a concern.

Specification Testing

POSF Number	*Total Acid Number, mg KOH/g*	*Aromatics, % vol*	*Mercaptan Sulfur, % mass*	*Total Sulfur, % mass*	*Flash Point, deg C*
96-POSF-3219	0	18.3	0	0.04	54
96-POSF-3219 + 26 ppm DRA					
96-POSF-3219+ 35.2 ppm DRA	0.001	20.5	0	0.04	55
98-POSF-3497	0.002	8.4		0.0037	47
98-POSF-3497+ 35.2 ppm DRA	0	8	0	0	49
99-POSF-3593	0	19	0.002	0.2	48
99-POSF-3593+ 8.8 ppm DRA	0	18.49	0	0.21	48
99-POSF-3601	0	16	0	0	61
99-POSF-3601+ 8.8 ppm DRA	0	14.56	0	0.01	64
99-POSF-3602	0	24	0	0	50
99-POSF-3602+ 8.8 ppm DRA	0	23.54	0	0.02	53
99-POSF-3603	0	22	0	0	56
99-POSF-3603+ 8.8 ppm DRA	0	19.8	0	0.02	59
99-POSF-3627	0	20	0	0	49
99-POSF-3627+ 8.8 ppm DRA	0	20.4	0	0.02	50
99-POSF-3627+ 35.2 ppm DRA	0	22	0	0	51
99-POSF-3633	0.01	15	0	0	51
99-POSF-3633+ 8.8 ppm DRA	0	15.8	0	0.02	53
99-POSF-3638	0	12	0.001	0	47
99-POSF-3638+ 8.8 ppm DRA	0	12.2	0	0.02	50
99-POSF-3638+ 35.2 ppm DRA	0	14	0.001	0	49
99-POSF-3639	0.01	15	0	0.1	46
99-POSF-3639+ 8.8 ppm DRA	0	15	0	0.06	48
99-POSF-3639+ 26 ppm DRA					
99-POSF-3639+ 35.2 ppm DRA	0	16	0	0.1	48
99-POSF-3639+ 44 ppm DRA					
99-POSF-3640	0	17	0	0	54
99-POSF-3640+ 8.8 ppm DRA	0	15.6	0	0.01	56

Table III.3-1 Specification Testing

Specification Testing continued

POSF Number	*Freezing Point, deg C (Automatic)*	*Viscosity @ -20 deg C*	*Smoke Point, mm*	*Copper Strip Corrosion*	*Existent Gum, mg/100mL*	*Water Reaction*
96-POSF-3219	-46	5.2	21	1a	0.8 / 4.6 **	1
96-POSF-3219 + 26 ppm DRA					2.8	
96-POSF-3219+ 35.2 ppm DRA	-46	5.2	21	1a	3.6 / 4.8 **	1
98-POSF-3497	-64	4.1	25	1a	2.6	1
98-POSF-3497+ 35.2 ppm DRA	-61	4.2	26	1b	2.4	1
99-POSF-3593	-43	5.9	21	1a	0.3	1b
99-POSF-3593+ 8.8 ppm DRA	-43	5.5	27	1a	0.2	1b
99-POSF-3601	-48	5	24	1a	0.1	1b
99-POSF-3601+ 8.8 ppm DRA	-48	5	27	1a	0	1b
99-POSF-3602	-54	5.9	20	1a	0	1b
99-POSF-3602+ 8.8 ppm DRA	-54	5.4	25	1a	0	1b
99-POSF-3603	-47	5	19	1a	0	1b
99-POSF-3603+ 8.8 ppm DRA	-48	5	26	1a	0.2	1b
99-POSF-3627	-50	6	20	1a	0	1b
99-POSF-3627+ 8.8 ppm DRA	-50	5.6	20	1a	0.4	1b
99-POSF-3627+ 35.2 ppm DRA	-50	5.3	19	1b	2.2	1
99-POSF-3633	-56	4	23	1a	1	1b
99-POSF-3633+ 8.8 ppm DRA	-55		23	1a	0.2	1b
99-POSF-3638	-53	4	25	1a	0.3	1b
99-POSF-3638+ 8.8 ppm DRA	-53	4	24	1a	0	1b
99-POSF-3638+ 35.2 ppm DRA	-53	4	22	1a	2.4	1
99-POSF-3639	-43	6.8	22	1a	0.7	1b
99-POSF-3639+ 8.8 ppm DRA	-43	6.2	24	1a	0.4	1b
99-POSF-3639+ 26 ppm DRA					5.2	
99-POSF-3639+ 35.2 ppm DRA	-43	6.3	22	1b	5 / 5.2 **	1
99-POSF-3639+ 44 ppm DRA					5.4	
99-POSF-3640	-48	5.4	20	1a	0	1b
99-POSF-3640+ 8.8 ppm DRA	-46	5.9	24	1a	0.2	1b

** shows repeated tests

Table III.3-1 Continued

Specification Testing continued

POSF Number	*Conductivity, pS/m*	*Distillation (10% Recovered)*	*Distillation (50% Recovered)*	*Distillation (90% Recovered)*	*Distillation (FBP, deg C)*
96-POSF-3219	5	184	208	245	263
96-POSF-3219 + 26 ppm DRA					
96-POSF-3219+ 35.2 ppm DRA	5	183	208	245	262
98-POSF-3497	440	170	193	226	251
98-POSF-3497+ 35.2 ppm DRA	595	174	195	227	250
99-POSF-3593	0	177	206	253	270
99-POSF-3593+ 8.8 ppm DRA	0	174	205	253	270
99-POSF-3601	0	190	206	231	243
99-POSF-3601+ 8.8 ppm DRA	0	189	206	231	244
99-POSF-3602	0	180	208	238	258
99-POSF-3602+ 8.8 ppm DRA	0	180	208	239	259
99-POSF-3603	0	188	207	239	254
99-POSF-3603+ 8.8 ppm DRA	0	185	207	238	255
99-POSF-3627	0	179	206	249	264
99-POSF-3627+ 8.8 ppm DRA	0	178	206	248	265
99-POSF-3627+ 35.2 ppm DRA	0	179	206	249	267
99-POSF-3633	0	174	191	225	243
99-POSF-3633+ 8.8 ppm DRA	0	173	191	225	244
99-POSF-3638	0	176	195	221	235
99-POSF-3638+ 8.8 ppm DRA	0	174	195	221	237
99-POSF-3638+ 35.2 ppm DRA	0	176	195	222	238
99-POSF-3639	0	180	217	262	286
99-POSF-3639+ 8.8 ppm DRA	0	181	218	263	287
99-POSF-3639+ 26 ppm DRA					
99-POSF-3639+ 35.2 ppm DRA	0	179	218	263	290
99-POSF-3639+ 44 ppm DRA					
99-POSF-3640	0	183	209	246	262
99-POSF-3640+ 8.8 ppm DRA	0	184	210	247	263

Table III.3-1 Continued

Specification Testing continued

POSF Number	*Distillation (Residue, % vol)*	*Distillation (Loss, % vol)*	*Lubricity Test (BOCLE) wear scar, mm*	*Thermal Stability @ 260 deg C (Tube Rating Visual)*	*Thermal Stability @ 260 deg C (Change in Press., mm Hg)*
96-POSF-3219	1.1	1	0.55	2	1
96-POSF-3219 + 26 ppm DRA					
96-POSF-3219+ 35.2 ppm DRA	1.2	1.1	0.57	1	5
98-POSF-3497	0.5	0.5	0.62	1	0
98-POSF-3497+ 35.2 ppm DRA	1.2	1.1	0.6	1	2
99-POSF-3593	1.5	1.1	0.73	2	3
99-POSF-3593+ 8.8 ppm DRA	1.5	1.4	0.74	2	2
99-POSF-3601	1.2	1.1	0.68	1	1
99-POSF-3601+ 8.8 ppm DRA	1.2	1.5	0.58	1	5
99-POSF-3602	1.2	1.2	0.69	2	3
99-POSF-3602+ 8.8 ppm DRA	1.3	0.7	0.65	1	1
99-POSF-3603	1.2	1.4	0.73	3	5
99-POSF-3603+ 8.8 ppm DRA	1.3	0.5	0.74	1	3
99-POSF-3627	1.3	1.4	0.64	1	1
99-POSF-3627+ 8.8 ppm DRA	1.4	0.8		1	4
99-POSF-3627+ 35.2 ppm DRA	0.9	1.1	0.69	2	4
99-POSF-3633	1	0.9	0.55	1	4
99-POSF-3633+ 8.8 ppm DRA	1.4	0.3	0.58	1	2
99-POSF-3638	1.3	1.1	0.58	1	5
99-POSF-3638+ 8.8 ppm DRA	1.2	0.8		1	0
99-POSF-3638+ 35.2 ppm DRA	1	0.9	0.58	1	3
99-POSF-3639	1.4	1.4	0.61	1	5
99-POSF-3639+ 8.8 ppm DRA	1.5	1.4	0.6	1	0
99-POSF-3639+ 26 ppm DRA					
99-POSF-3639+ 35.2 ppm DRA	1.2	1.1	0.65	2	3
99-POSF-3639+ 44 ppm DRA					
99-POSF-3640	1.2	1.4	0.58	1	0
99-POSF-3640+ 8.8 ppm DRA	1.2	1.6	0.6	1	2

Table III.3-1 Continued

4. LOW TEMPERATURE TESTING

A low temperature test system that was established for evaluating potential low temperature additives for U-2 aircraft fuel was used for these tests. In the system, shown as Figure III. 4-1, fuel passes from the tank (7.6 L) through stainless-steel tubing (1.9 cm OD x 1.7 cm ID) which is in series with a screen and valve. The screen (8 mesh) is typical of a boost pump inlet screen and is considered a likely location for flow blockage. The tank, fuel line, valve, and screen are contained within a chamber that is capable of operating down to -73 °C. The fuel exits the cooled chamber and is collected in a tank that is on scale outside the chamber. The scale is used to measure the mass of fuel flowing from the fuel tank and screen. Thus, a timer used in combination with the mass measurement provides an average mass flow rate of the fuel exiting the chamber. In addition, the fuel tank is pressurized with nitrogen such that the internal pressure of the tank was 10.5 kPa above the ambient pressure. This pressure difference is similar to that used for pressurization of aircraft wing tanks.

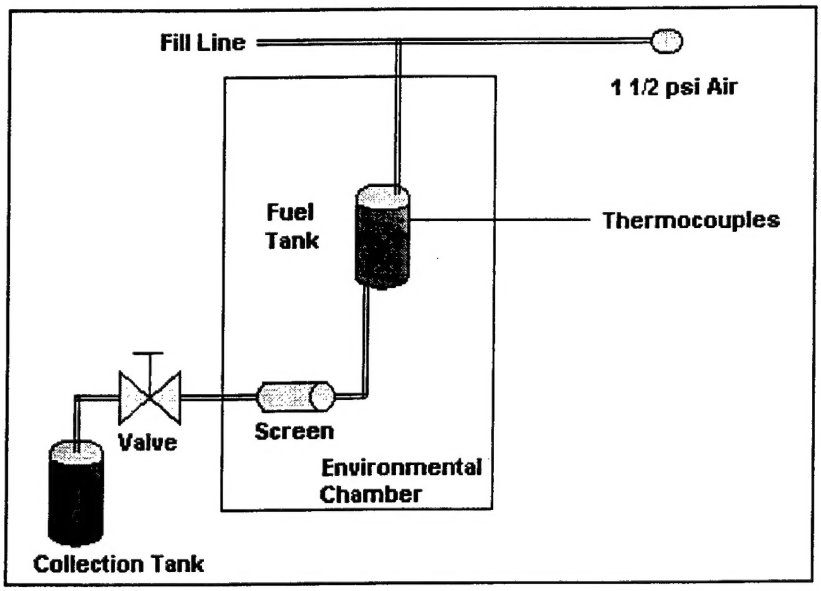


Figure III.4-1. System for Low-Temperature Flow Reduction and Hold-Up Experiments.

The bulk fuel temperatures within the fuel tank were measured by thermocouples (type T) at two locations within the tank and one location directly in the center of the screen. The chamber was set to the desired cooling temperature and the fuel allowed to cool for 16 hours. The fuel in the tank was maintained at the desired steady-state temperature for at least one hour before flow is permitted from the fuel tank. Differences in mass flow rate at a given temperature and source pressure provide an indication of the flow resistance through the tubes and the screen. Since the mass of fuel is known before initiating flow, the mass of fuel that solidifies within the tank (fuel hold-up) is determined from measurement of the mass of fuel collected in the tank outside of the cooling chamber [10].

The tests were conducted in POSF-3219 fuel at –60 and –65 °F, respectively. The results of these tests are shown in Table III.4-1. The test results of the fuel without the additive are included for comparison purposes. The holdup was higher with the additive

than with the baseline fuel. The additive did not significantly effect the flow rate at –60°F. Since the actual freeze point was not effected; low temperature operation is not considered to be a problem with this additive.

Fuel	Holdup (%)	Flow (lb/min)
POSF 3219		
@-60°F	4	9.2
@-65°F	15	*not recorded
with DRA		
@-60°F	8	9
@-65°F	18	*not recorded

Note: *Flow was not recorded because strainer was partially blocked and impeded flow.

Table III.4-1. Low Temperature Test Results

CONCLUSION

The Baker FLO XS Pipeline Drag Reducer was put through a series of tests developed over the course of the JP-8+100 program. These tests were found to be accurate in predicting the impact of an additive on the thermal stability of jet fuel.

Based on the results of testing at a polymer concentration of 8.8 ppm, the Baker FLO XS drag-reducing additive had no deleterious impact on thermal stability of jet fuel up to 325°F bulk and 450°F wetted wall temperature. When added to the +100 additive package at the same concentration, it had no deleterious impact on thermal stability up to 375°F bulk and 500°F wetted wall conditions. Based on the results of the screening tests using a wide variety of fuels, Baker FLO XS is not sensitive to fuel types or treatments.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

API	American Petroleum Institute
ARSFSS	Advanced Reduced Scale Fuel System Simulator
BFA	Burner Feed Arm
DRA	Drag Reducing Additive, same as Pipeline Drag Reducer (PDR)
EDTST	Extended Duration Thermal Stability Test
FCOC	Fuel Cooled Oil Cooler
FDV	Flow Divider Valve
HLPS	Hot Liquid Process Simulator
ICOT	Isothermal Corrosion/Oxidation Test
JFTOT	Jet Fuel Thermal Oxidative Tester
NIFTR	Near Isothermal Flowing Test Rig
QCM	Quartz Crystal Microbalance